Appendix A: ARVO Paper

Binocular Viewing Mode Affects Spatio-temporal Contrast Threshold

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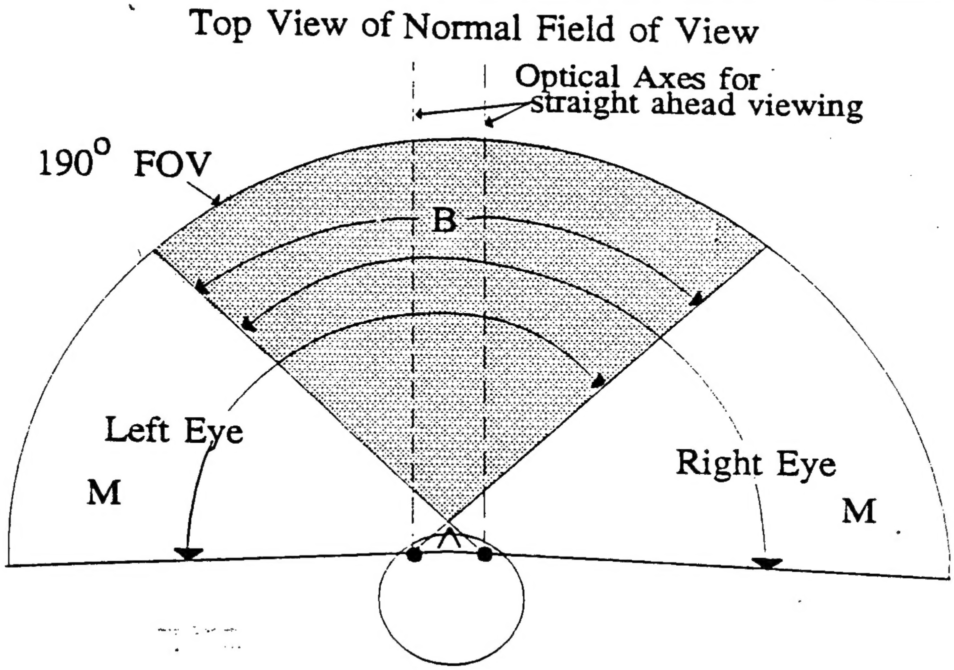
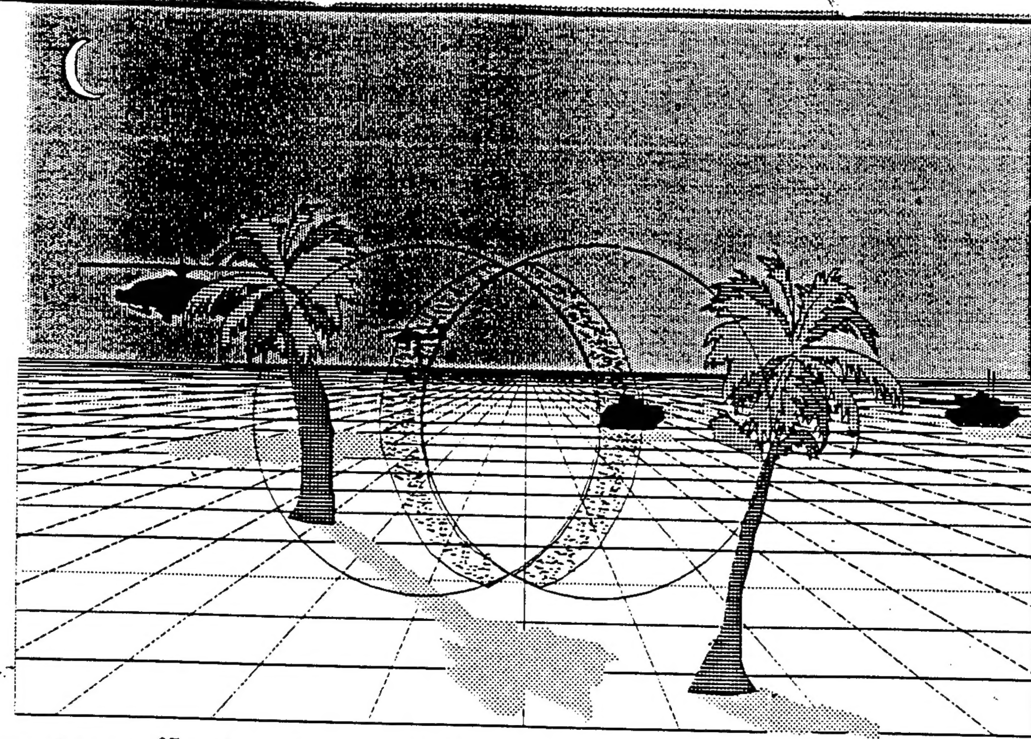
Purpose

The normal binocular field-of-view is indicated below.



The normal field-of-view is divergent, where the right eye's monocular region (M) is to the right of the binocular region (B) and the left eye's monocular region is to the left. The total field-of-view is normally around 190°.

If the field-of-view is reduced such as may occur in a helmet mounted display, a number of factors change, as shown below.



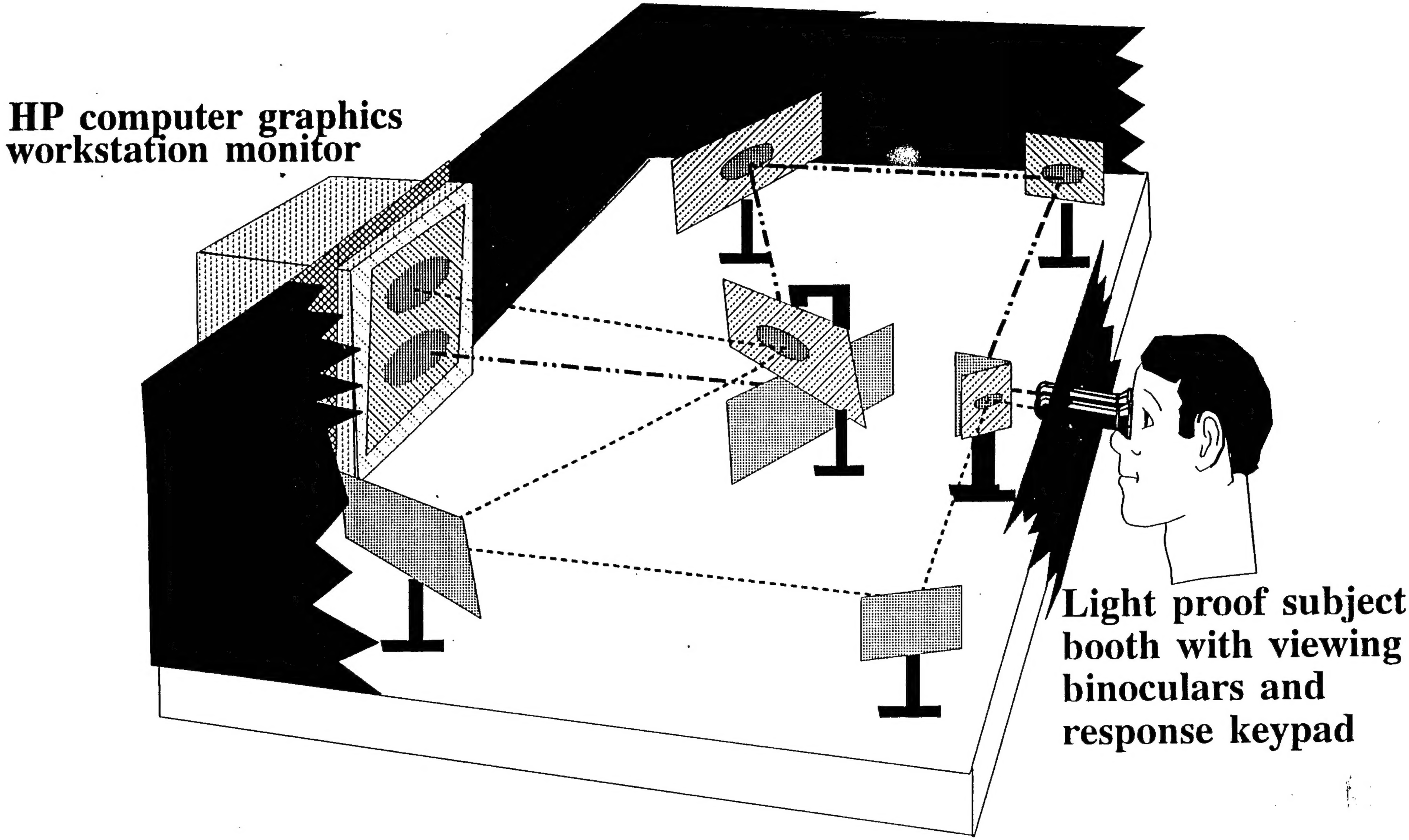
A helicopter pilot's view of the visual world using an *HMD in partial binocular overlap display mode.* The helicopter in the left visual field and the armored personnel carrier in the right visual field are each in monocular regions near the *Monocular/Binocular border.* If the right eye is viewing the circular region containing the armored personnel carrier, the display mode is *Divergent.* If instead, the left eye is viewing this region, the display mode is *Convergent.*

To increase the available field-of-view, the display may be presented in a *partial binocular overlap display mode.* (Convergent or divergent) as opposed to a *complete binocular overlap display mode,* where both eyes see the same image.

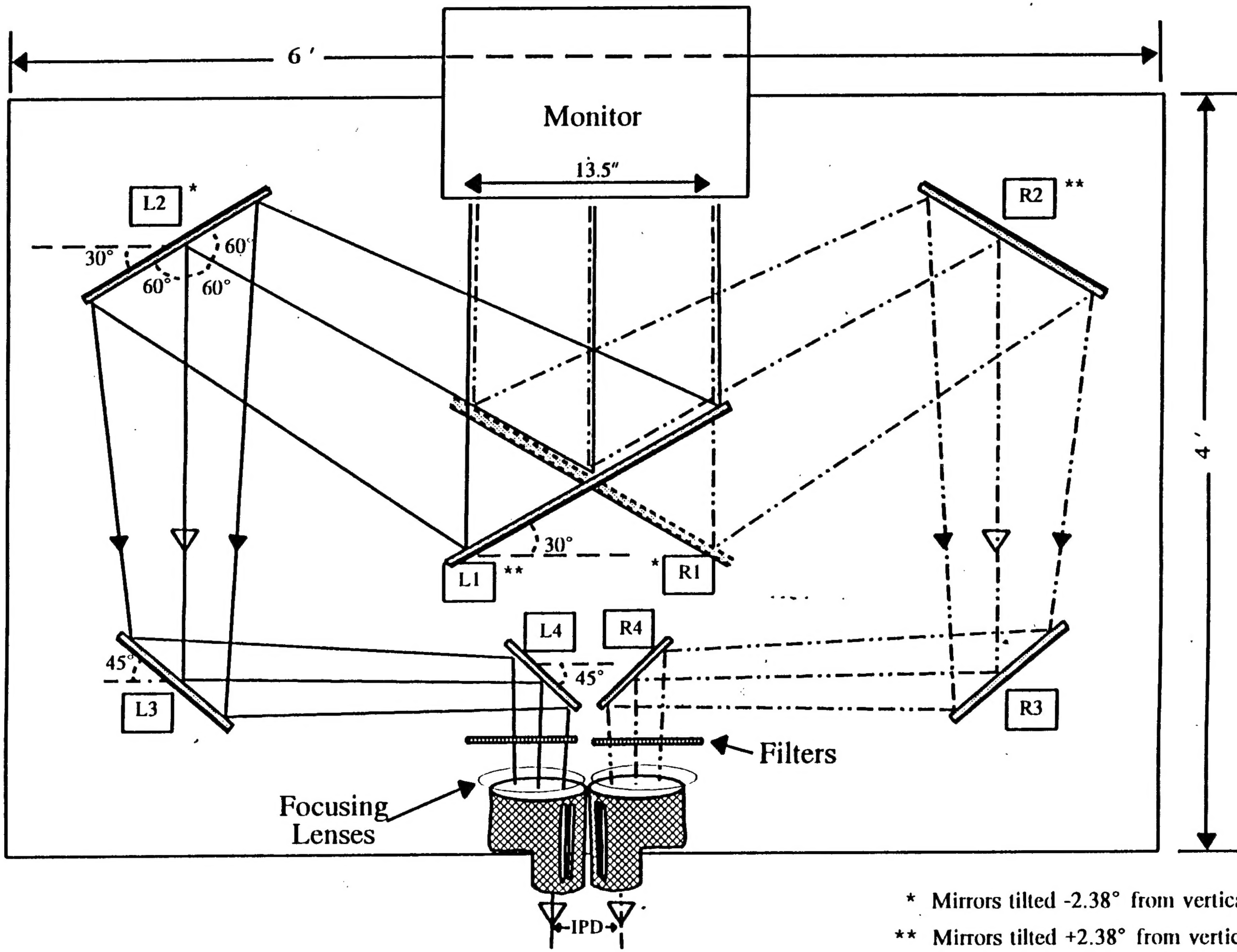
We quantified *changes in visual sensitivity across the field of view* for these *display modes* by measuring contrast thresholds of various probes in various positions.

EQUIPMENT

Optical table mirror configuration



Details of Optical Table Configuration

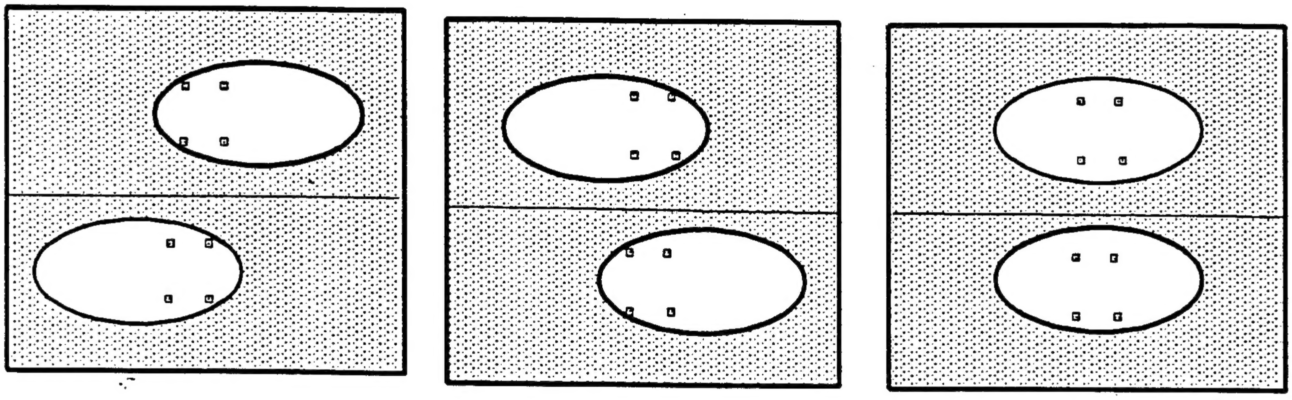


* Mirrors tilted -2.38° from vertical

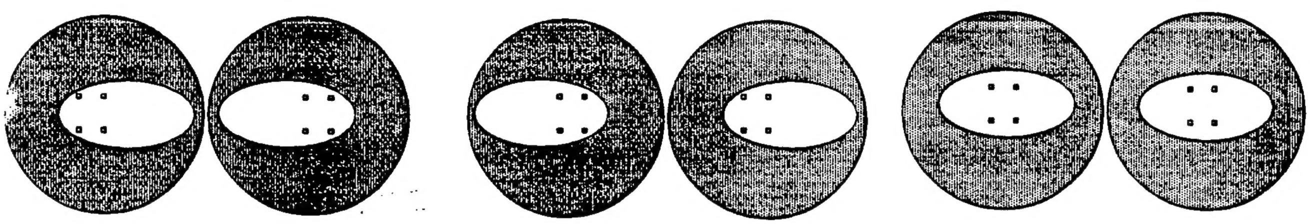
** Mirrors tilted +2.38° from vertical

Display Modes

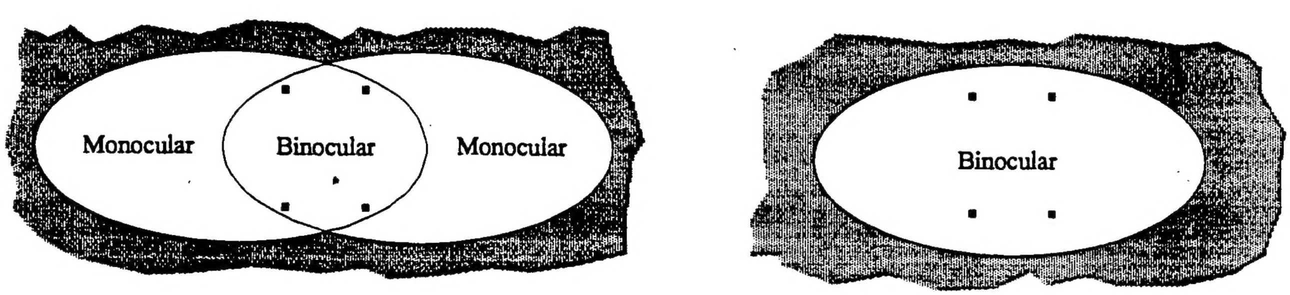
Convergent Display Mode | Divergent Display Mode | Complete Overlap Display Mode



Elliptical monocular fields on the monitor

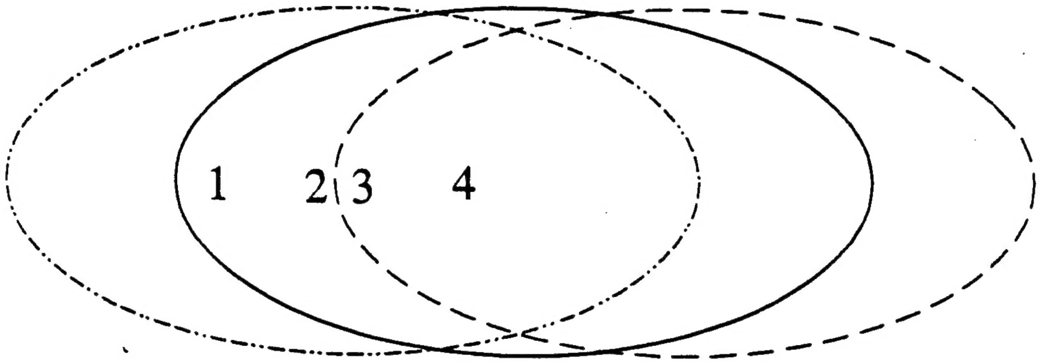


Through the Binoculars

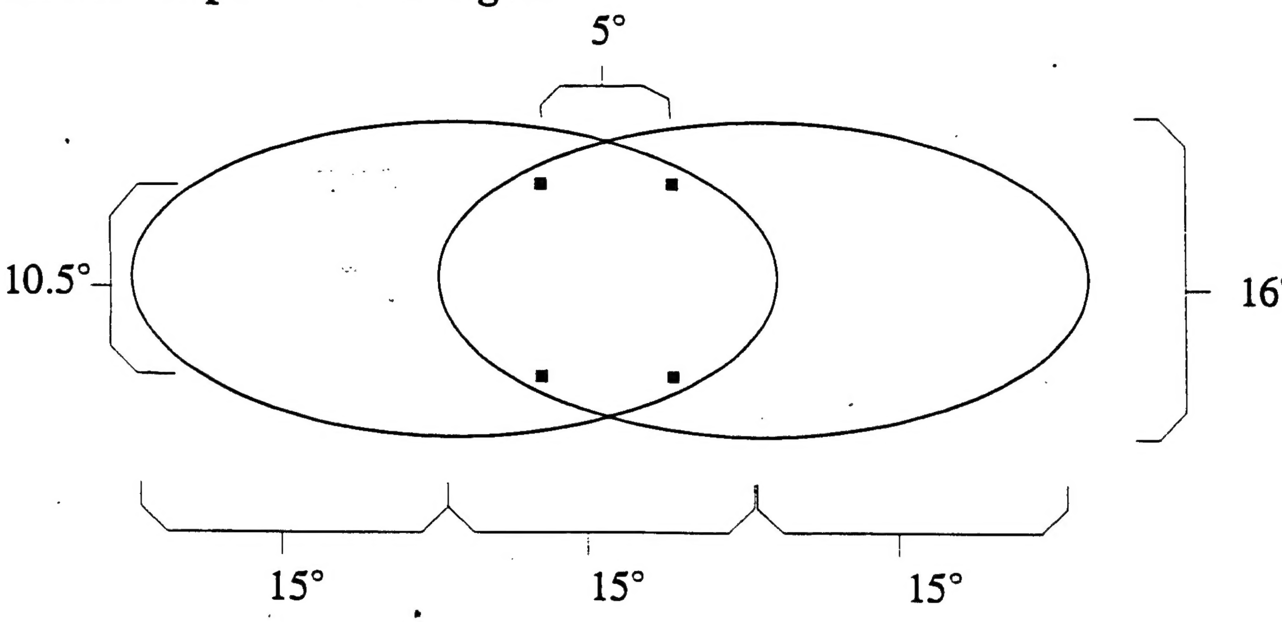


Field-of-view as seen by the observer

Note: small black squares are fusion locks



ɪhe relative positions of the elliptical monocular fields and the four probe positions are shown superimposed. Both eyes see the ellipse with the solid line in the *complete overlap display mode.* In the *divergent display mode,* the right eye sees the dashed ellipse on the right, and the left eye sees the dotted ellipse on the left. Conversely, in the *convergent mode,* the right eye sees the dotted ellipse on the left, and the left eye sees the dashed ellipse on the right.



The visual dimensions in degrees of visual angle are given to the right and below the overlapping monocular fields. The distances between fusion locks are given above and to the left. Monocular fields were 2 fL against a black background.

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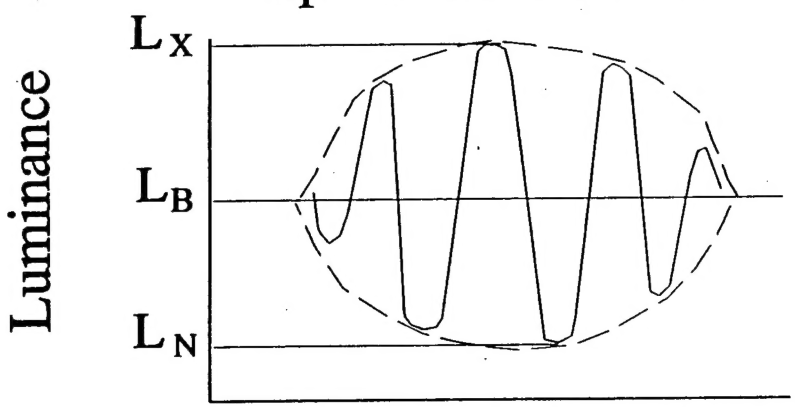
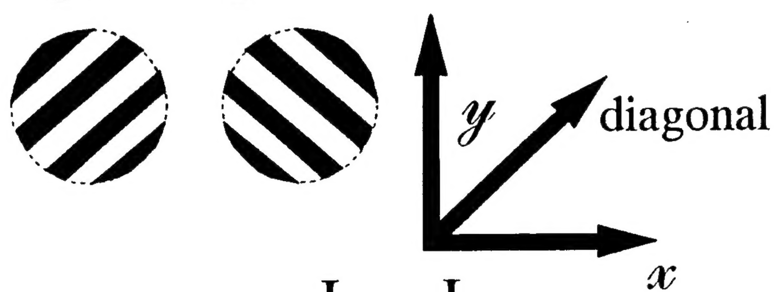
Spatial Modulation

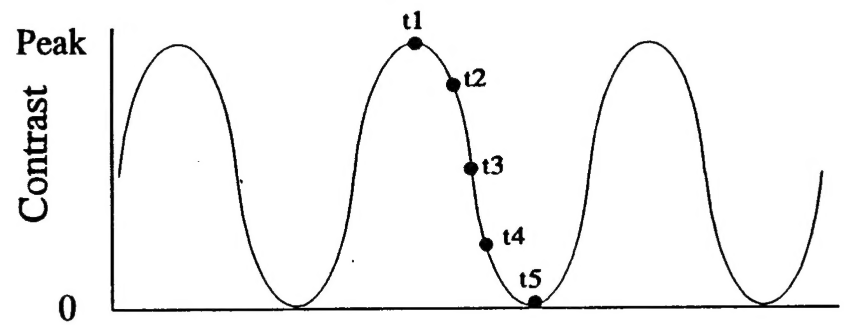


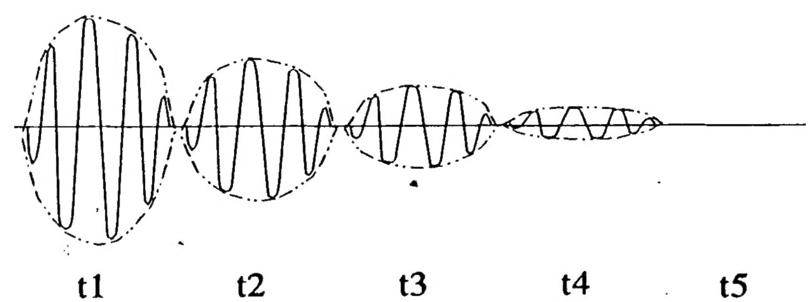
Diagonal Spatial Cross Section



$$\text{Contrast}=\frac{L_X - L_N}{L_X + L_N}$$

Temporal Modulation





Spatial cross section at five points in time.

Procedure

1. Eye exam
2. Equipment calibrated to subject's IPD.
3. Method of adjustment used to set contrast threshold of probe for determining orientation.

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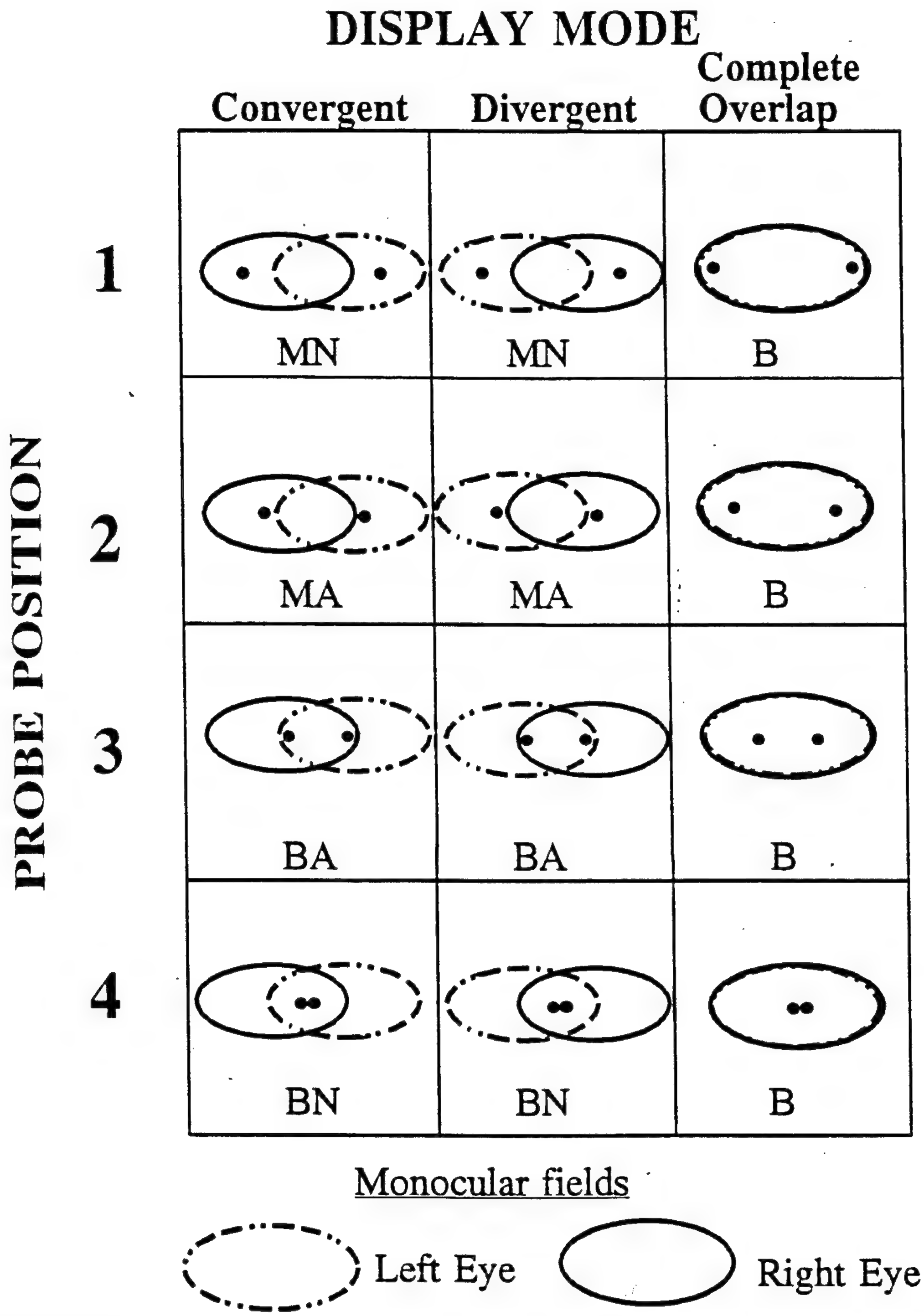
Design

All stimulus combinations were tested. These included: 3 display modes x 4 probe positions x 16 types of probe stimuli (4 spatial frequencies x 4 temporal frequencies). A single probe spatial frequency and position were run in a session, which included the three display modes x four temporal frequencies x three blocks. Right and left versions of each position were averaged. The following number of subjects were run in each position x spatial frequency combination.

Position	cpd: 8.48	4.24	2.12	1.07
1	17	22	23	18
2	23	26	27	20
3	25	26	25	17
4	17	19	21	15



Probe Positions

M = Monocular region
B = Binocular region

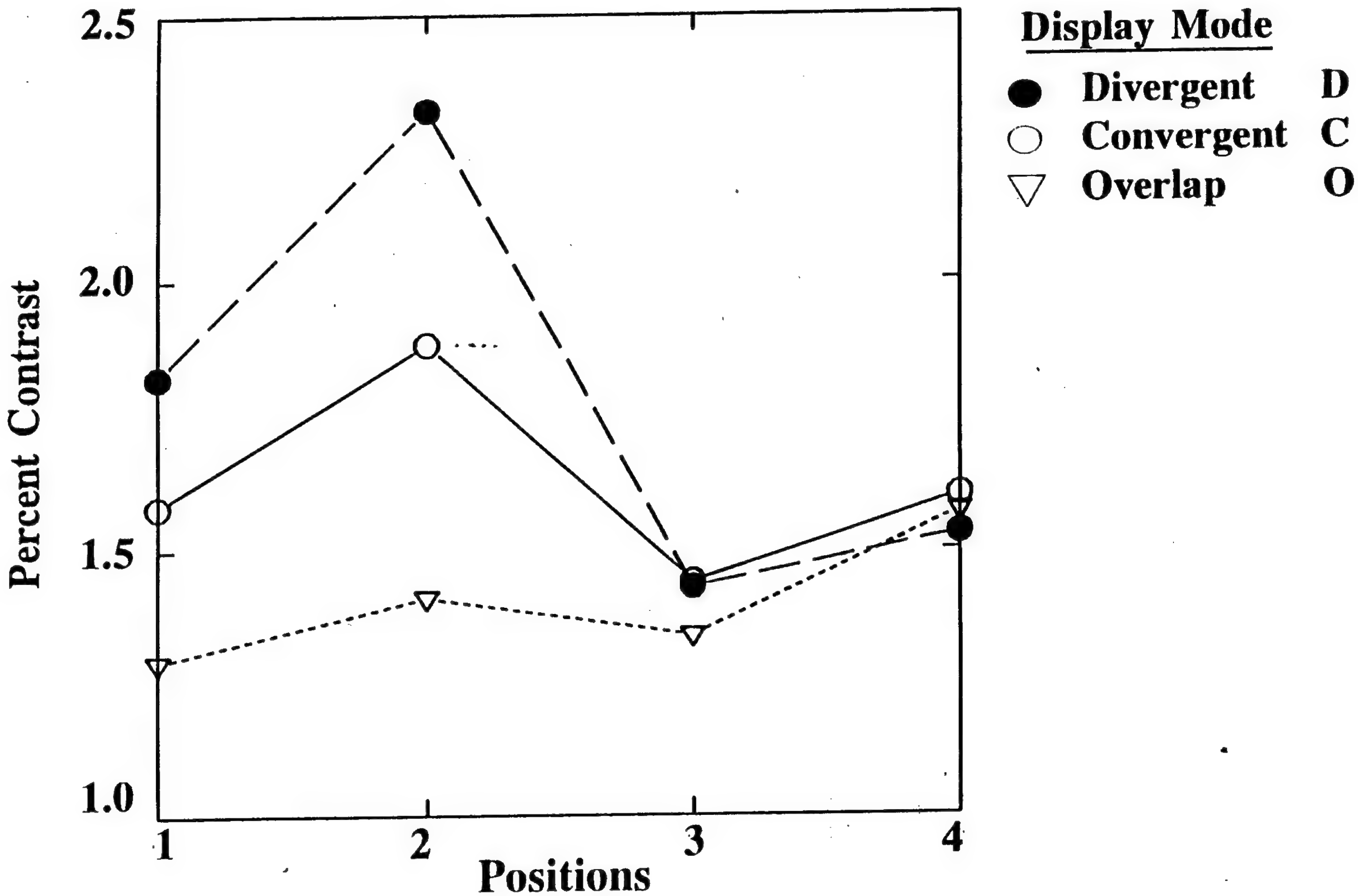
Distance of probe to monocular/binocular border

N = Nonadjacent, 2.03°
A = Adjacent, 0.08°

Relative locations of four probe positions (right side and left side versions), in the three display modes.

Contrast Threshold Results

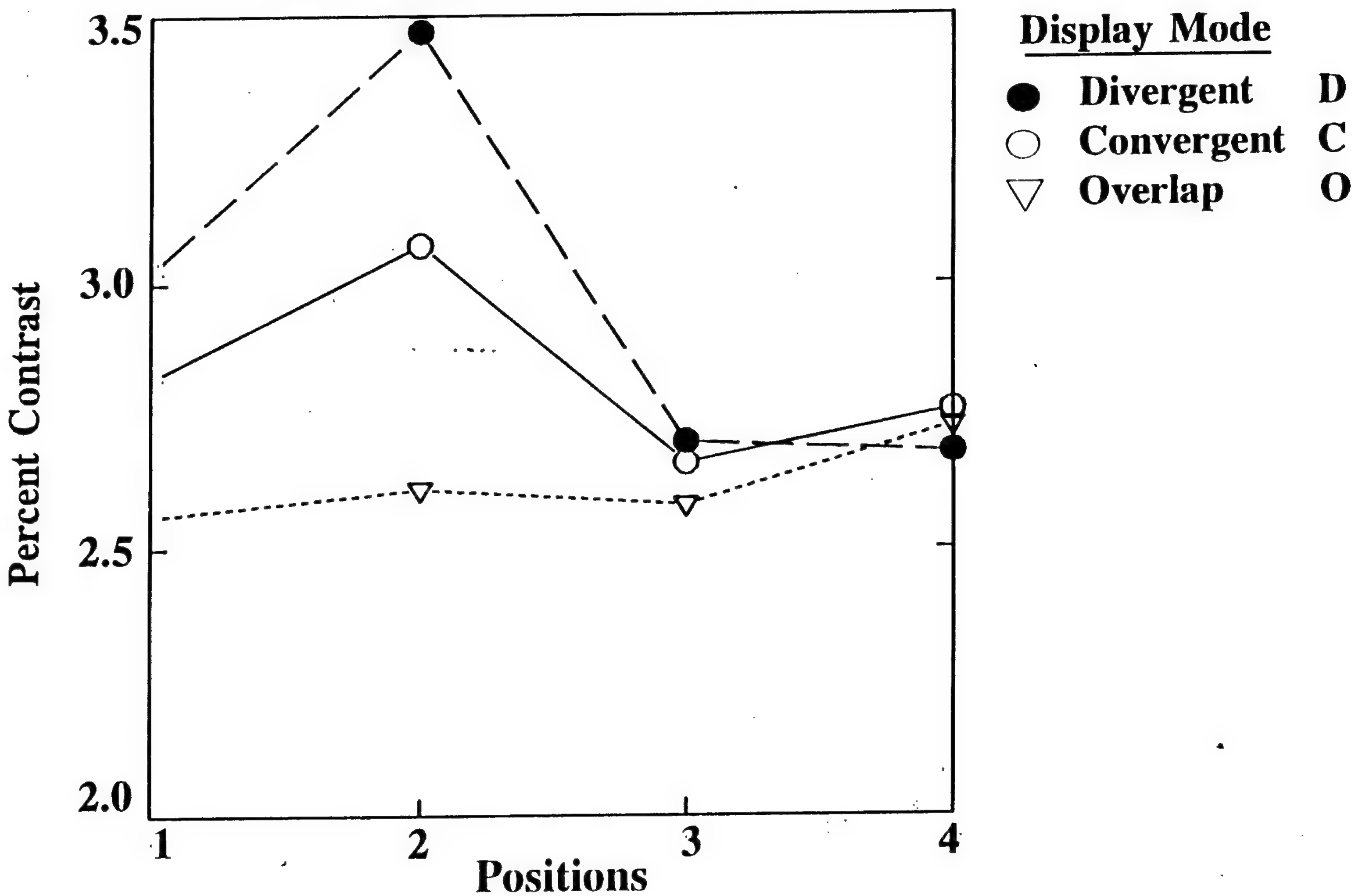
8.48 cpd   0 Hz



t-test	p<			
C v D	.05	.005	NS	NS
O v C	.01	*	.05	NS
O v D	.0005	*	.05	NS

* = p<.0001

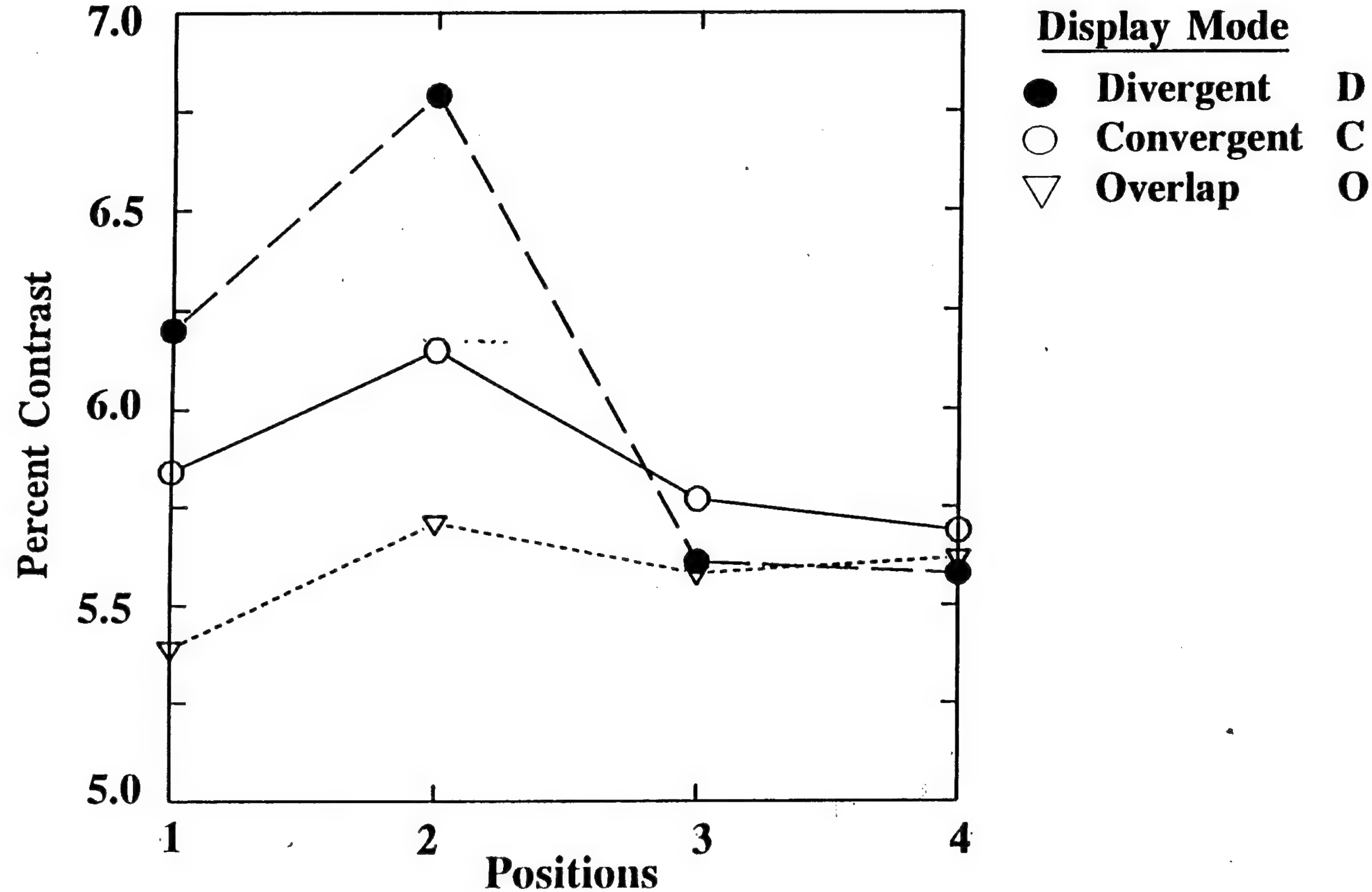
8.48 cpd 3.75 Hz



t-test	p<			
C v D	.05	.001	NS	NS
O v C	.005	*	NS	NS
O v D	*	*	.025	NS

* = p<.0001

8.48 cpd 15 Hz

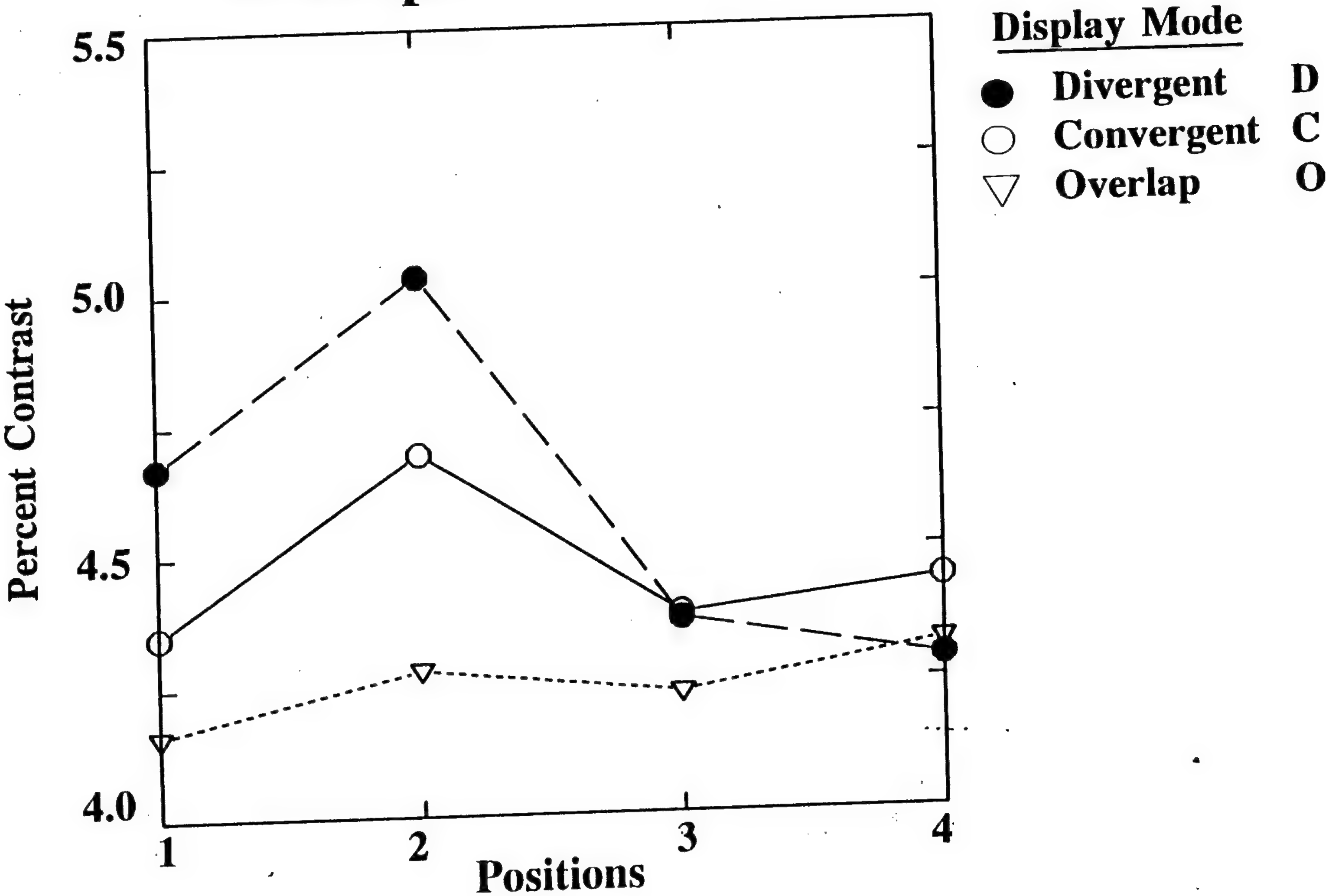


p<

t-test	1	2	3	4
C v D	.025	.00025	NS	NS
O v C	.01	*	.01	NS
O v D	*	*	NS	NS

* = p<.0001

8.48 cpd 7.5 Hz

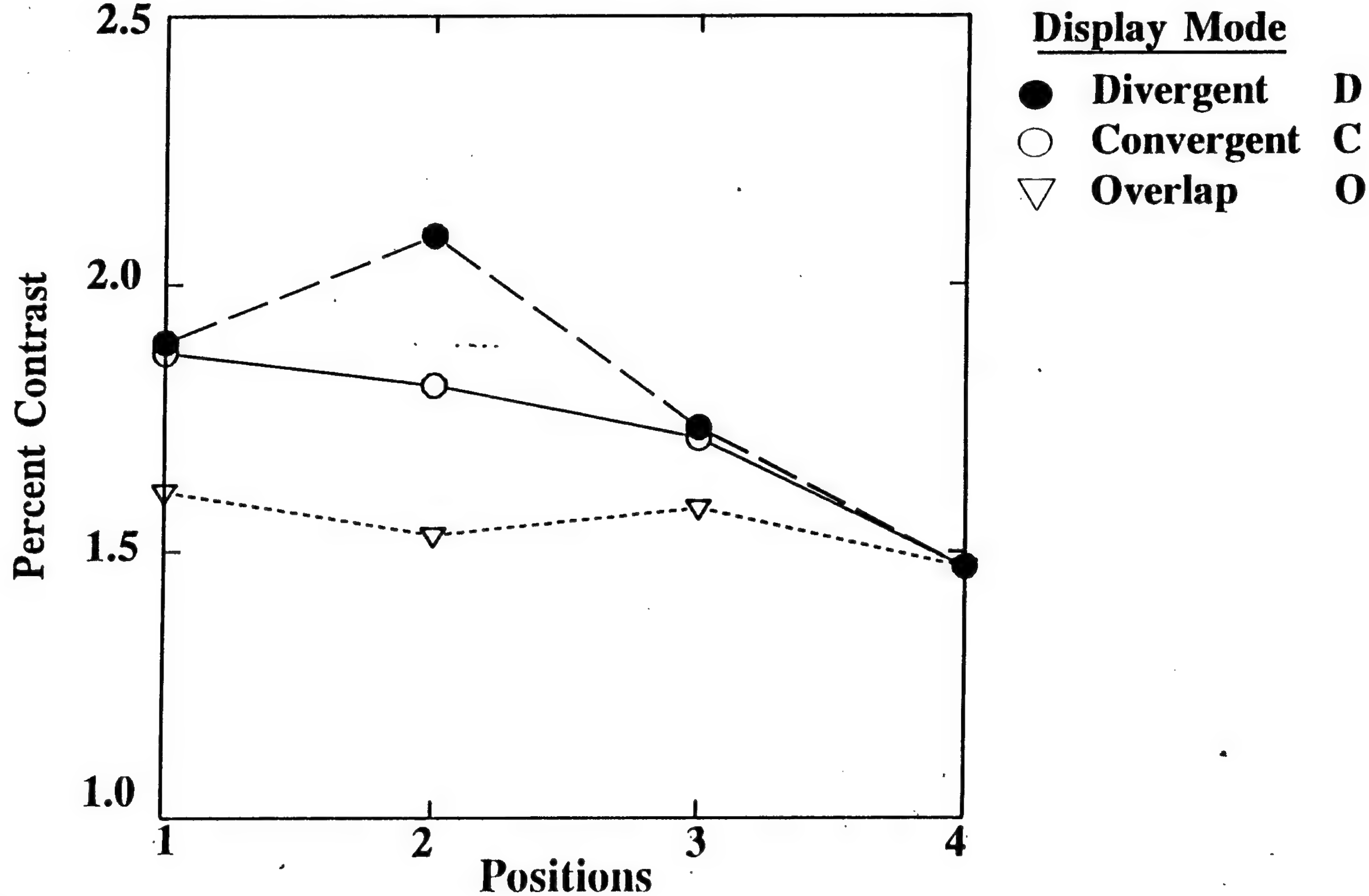


p<

t-test				
C v D	.01	.0025	NS	NS
O v C	.05	*	.025	NS
O v D	.0005	*	.025	NS

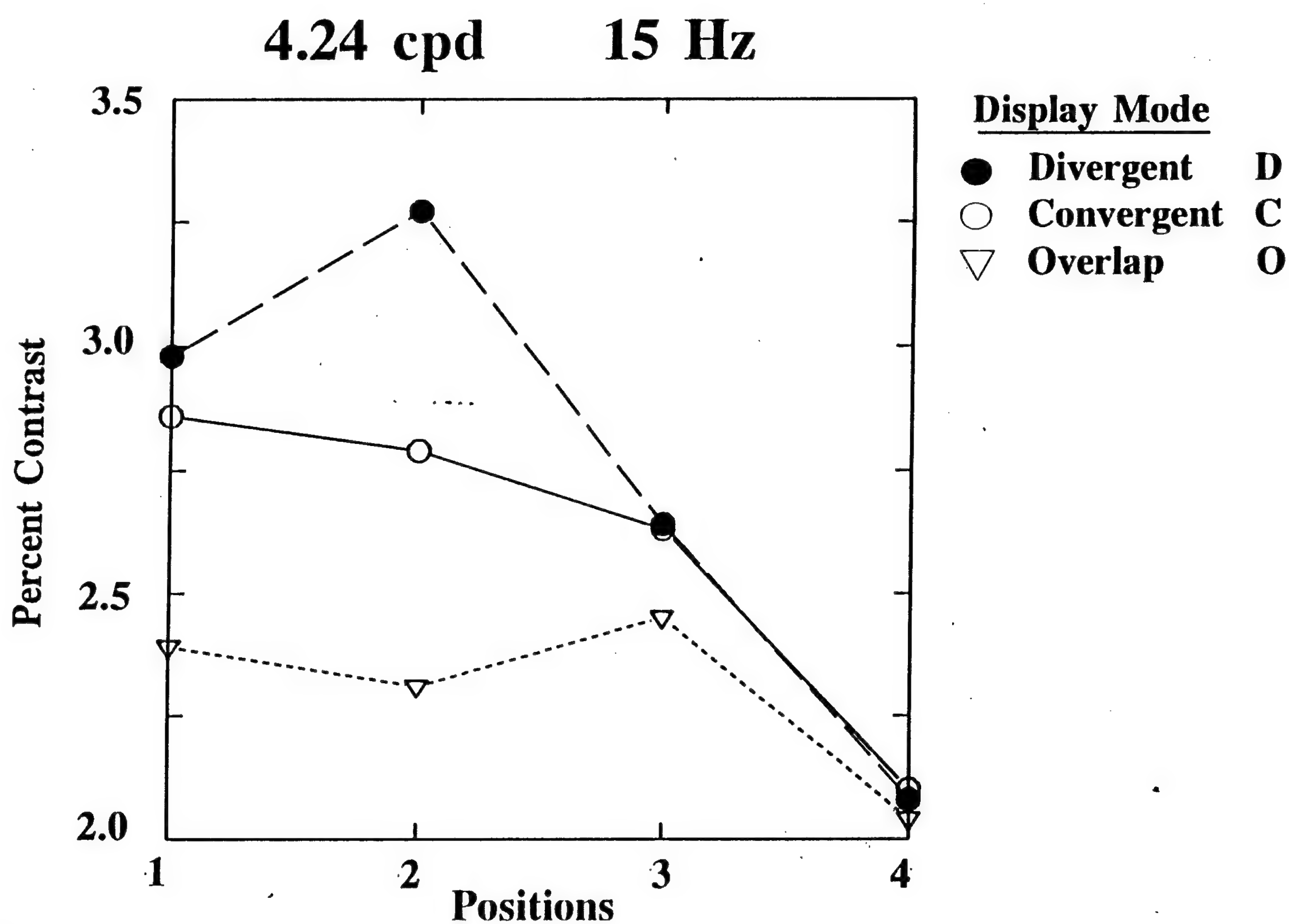
* = p<.0001

4.24 cpd 0 Hz



t-test	p<			
C v D	NS	.025	NS	NS
O v C	.00025	*	.025	NS
O v D	.0025	*	.01	NS

* = p<.0001



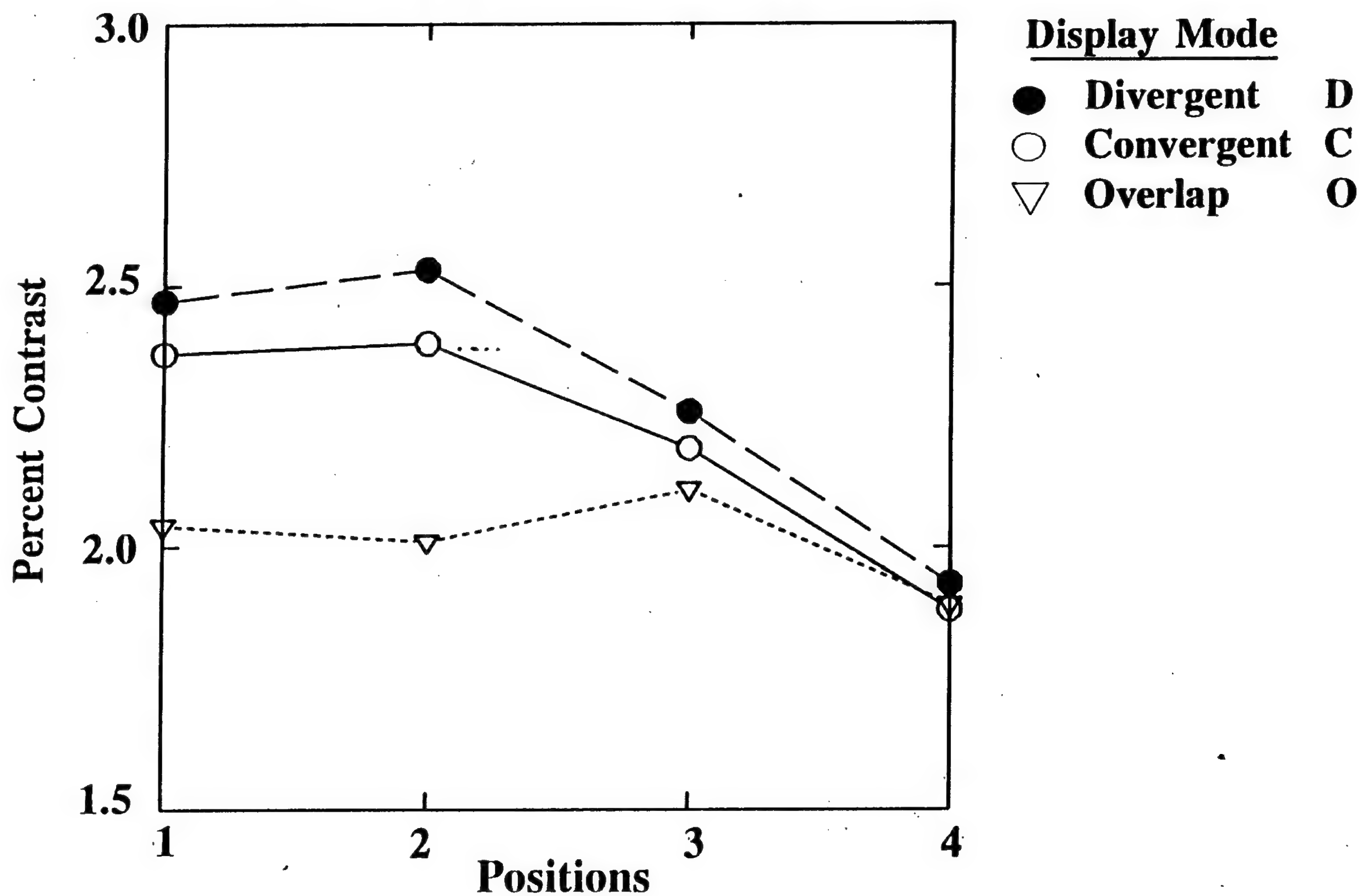
t-test

p<

C v D	NS	.01	NS	NS
O v C	.0025	*	.0025	NS
O v D	*	*	.01	NS

* = p<.0001

4.24 cpd   3.75 Hz

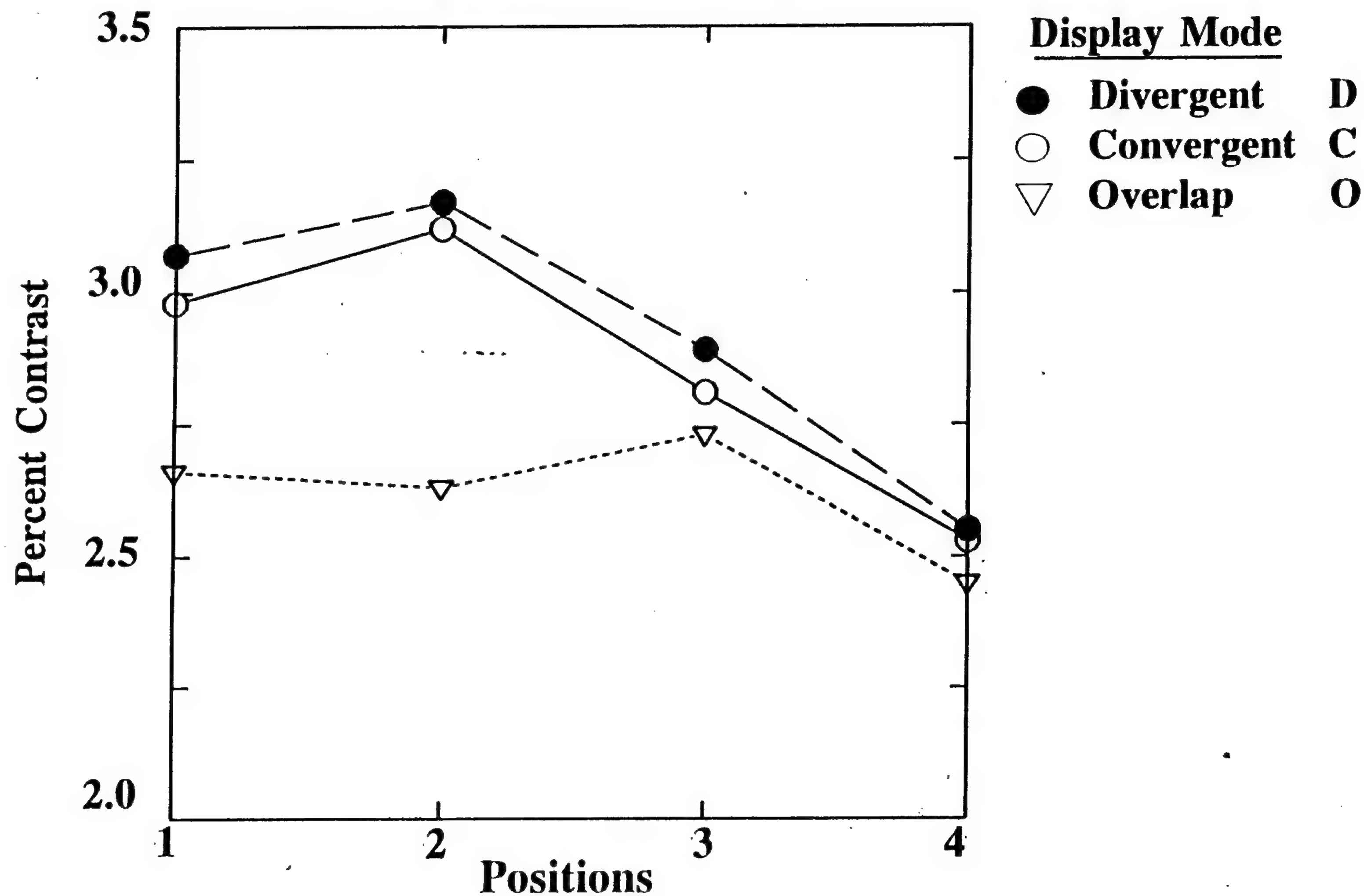


p<

t-test				
C v D	NS	NS	.05	NS
O v C	.0005	*	NS	NS
O v D	*	*	.0025	NS

* = p<.0001

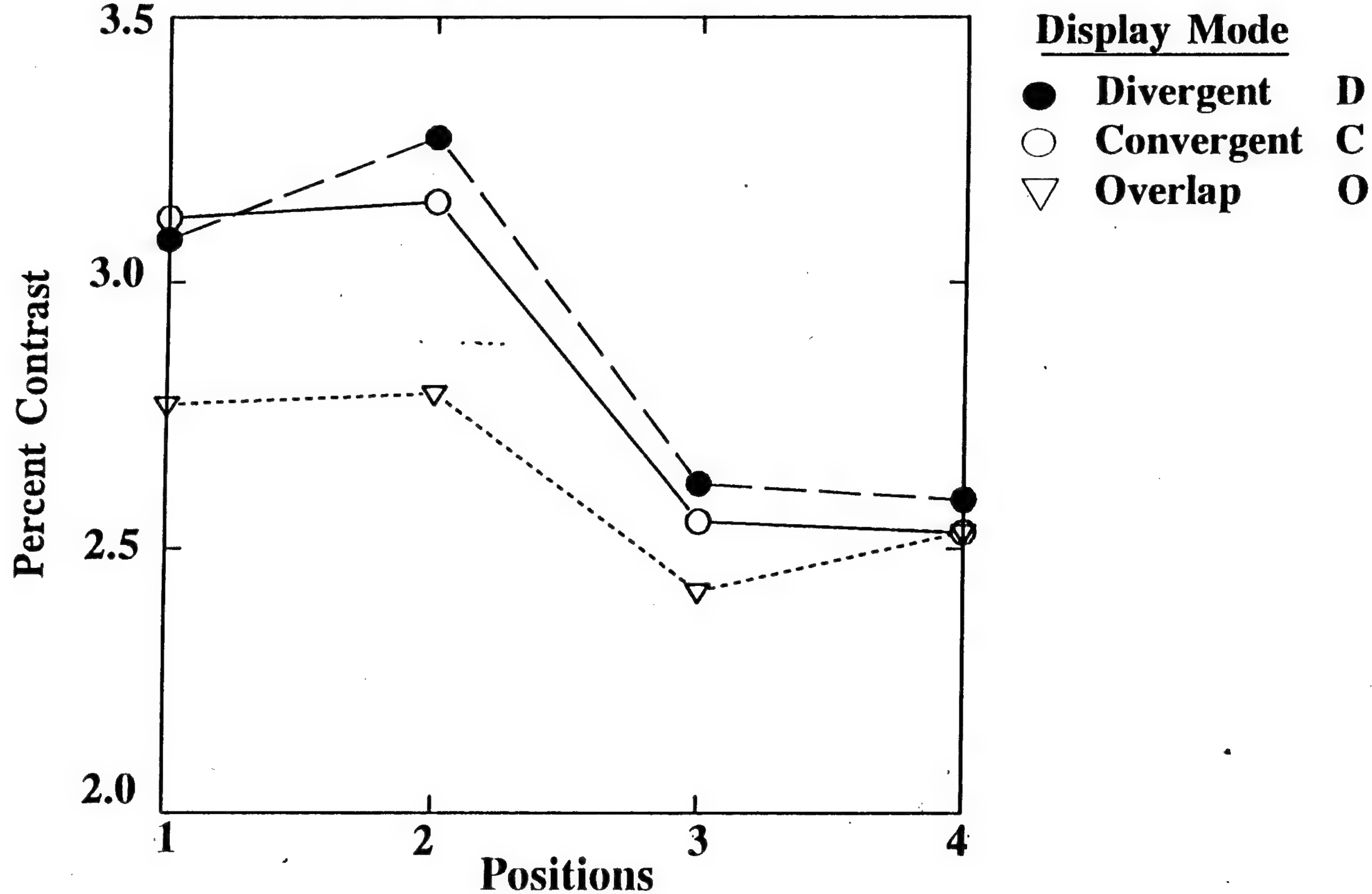
4.24 cpd 7.5 Hz



t-test	p<			
C v D	NS	NS	.05	NS
O v C	*	*	NS	.01
O v D	*	*	.01	.001

* = p<.0001

2.12 cpd 0 Hz

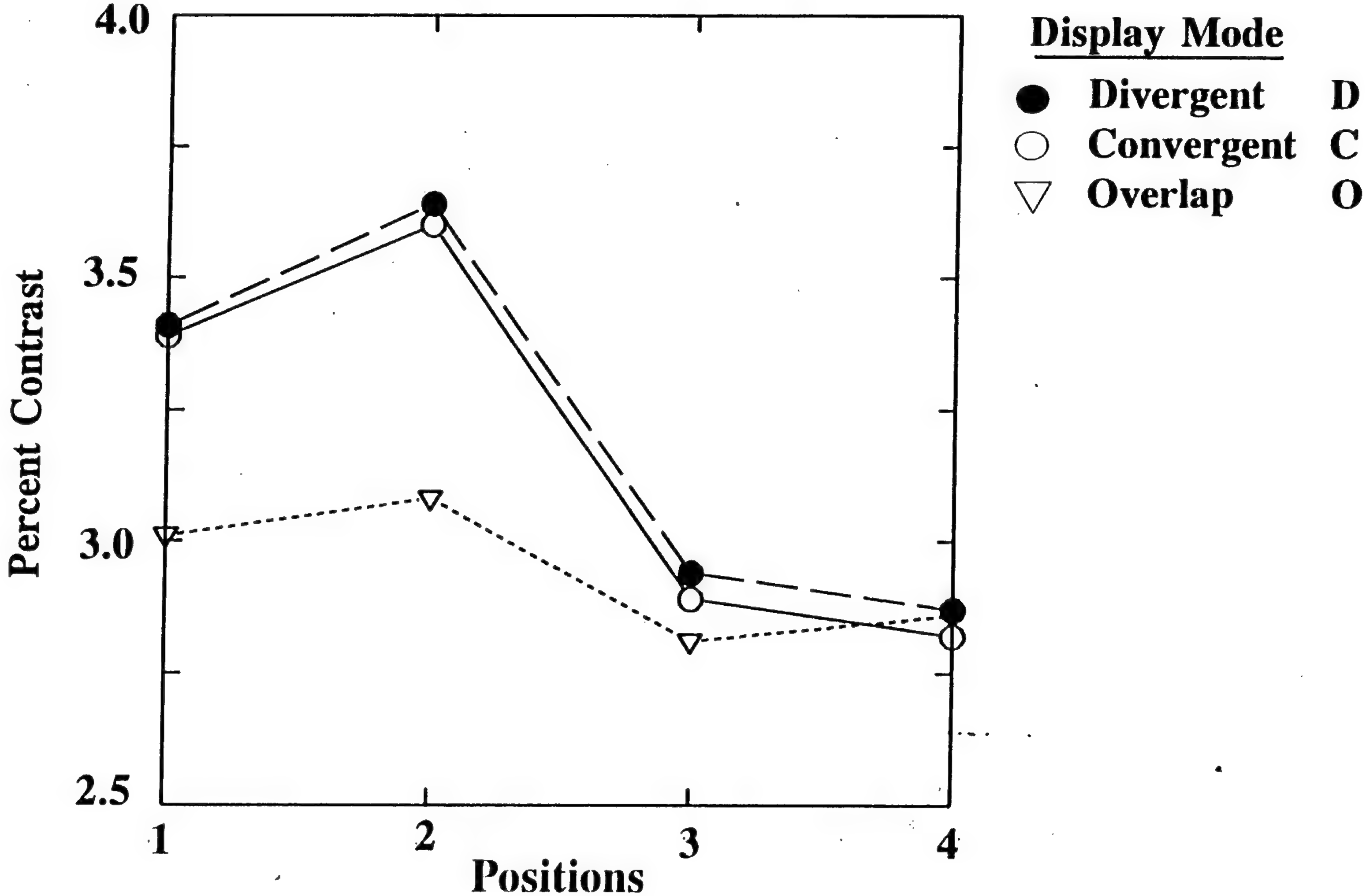


p<

t-test				
C v D	NS	NS	.05	NS
O v C	.00025	*	.0005	NS
O v D	*	*	.00025	NS

* = p<.0001

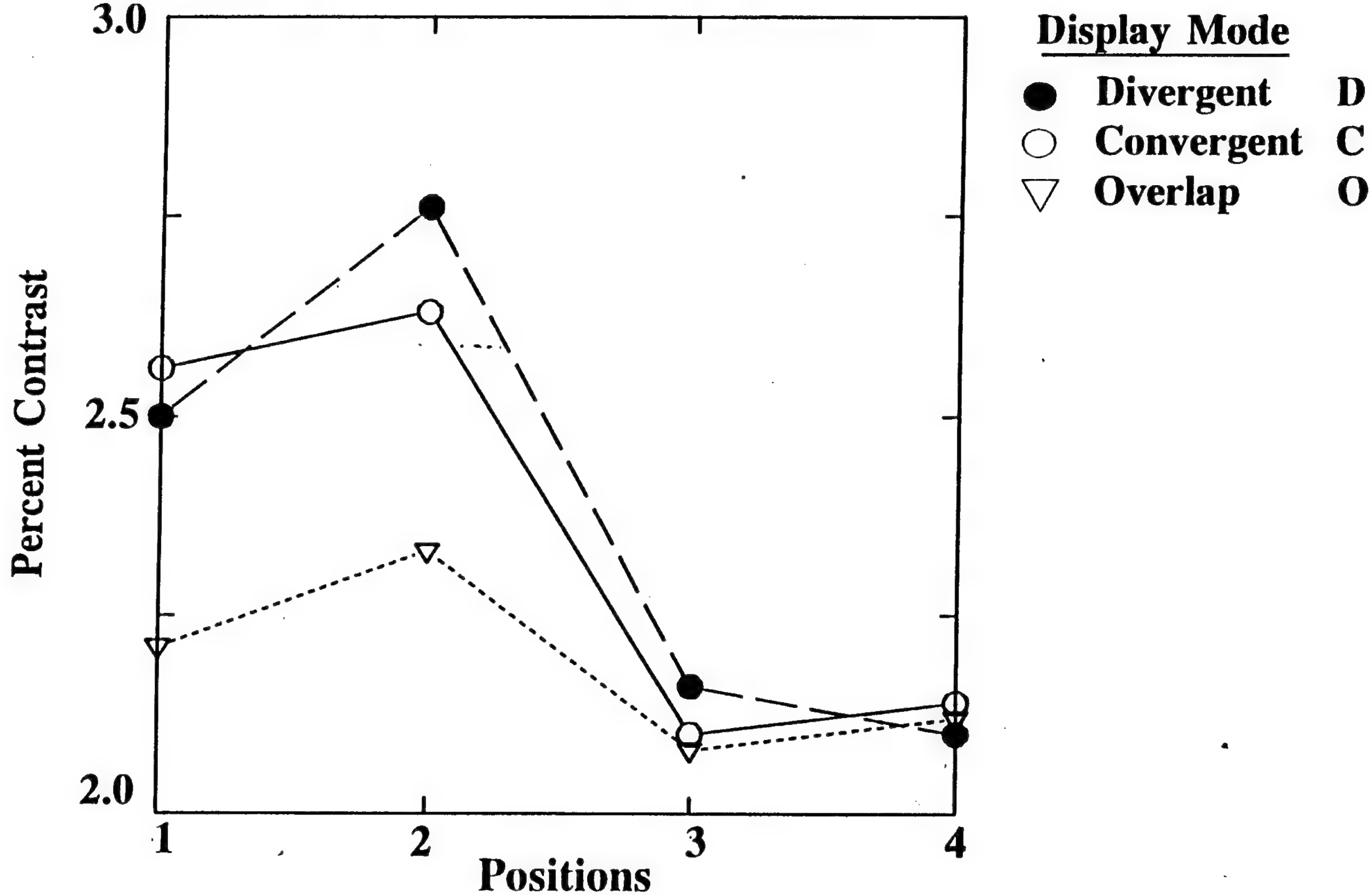
2.12 cpd 15 Hz



t-test	p<			
C v D	NS	NS	NS	NS
O v C	*	*	.025	NS
O v D	*	*	.005	NS

* = p<.0001

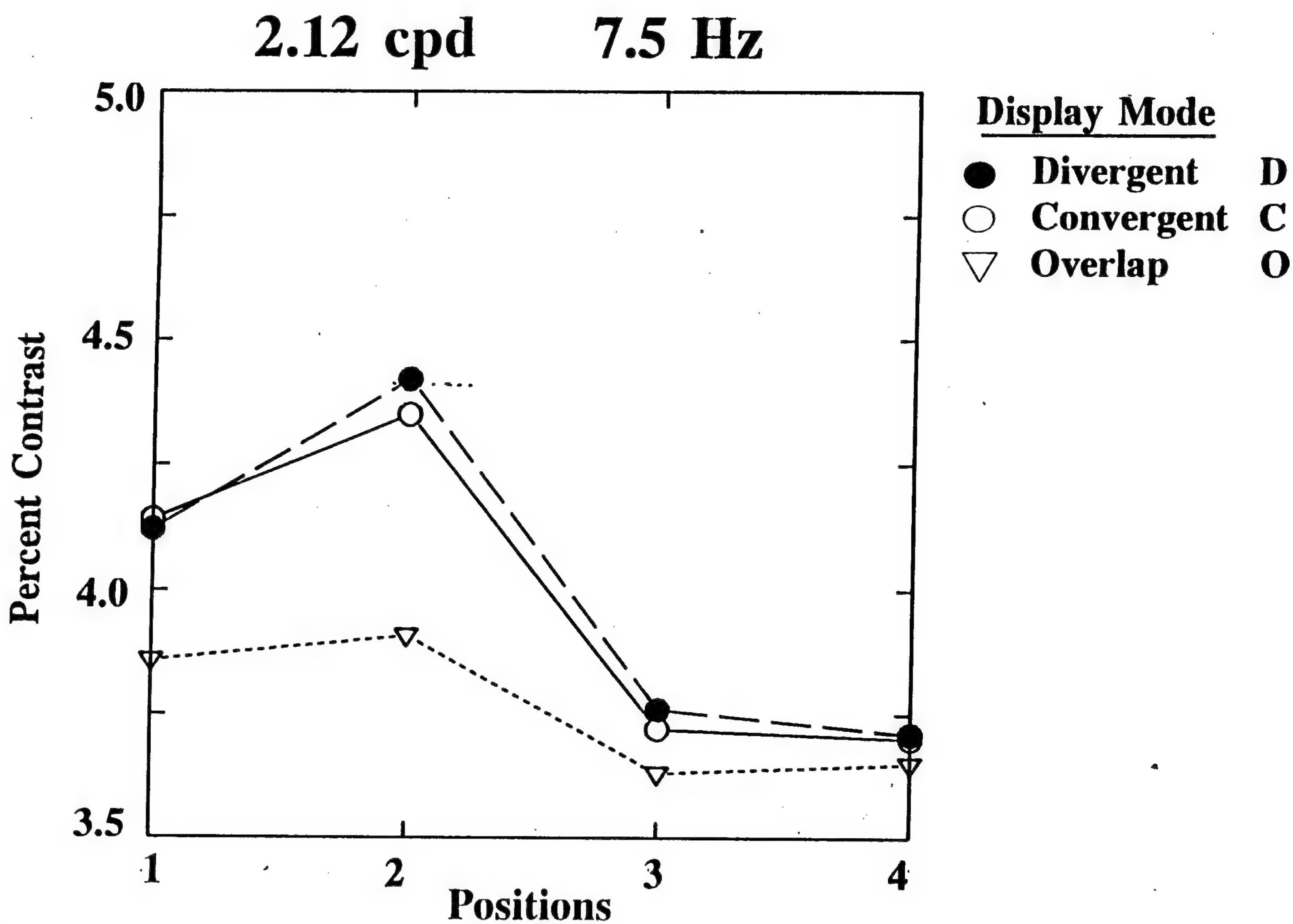
2.12 cpd 3.75 Hz



p<

t-test				
C v D	NS	NS	NS	NS
O v C	*	*	NS	NS
O v D	*	*	.025	NS

* = p<.0001



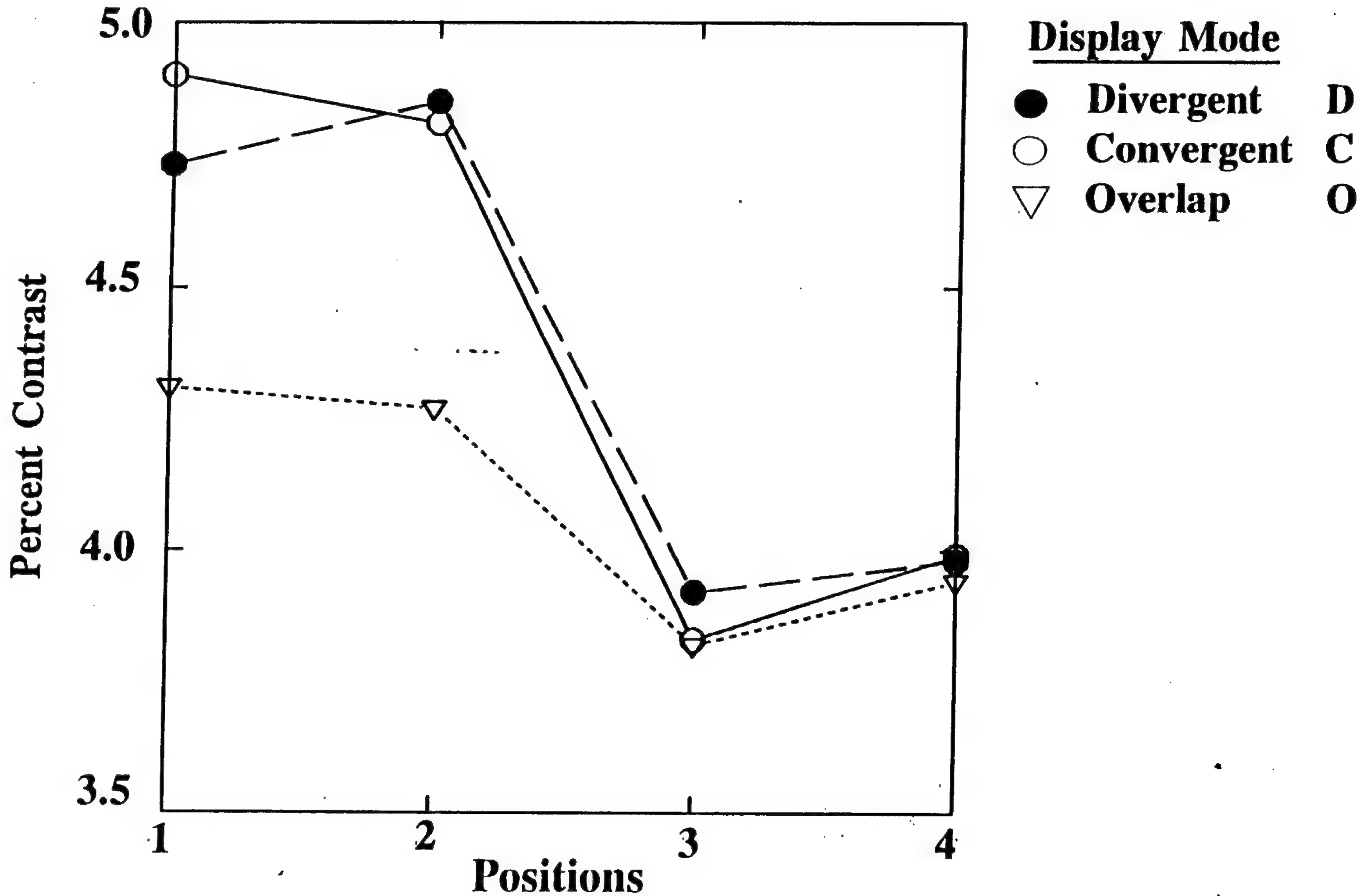
t-test

p<

t-test				
C v D	NS	NS	NS	NS
O v C	.00025	*	.01	NS
O v D	.0005	*	.0005	.05

* = p<.0001

1.06 cpd 0 Hz



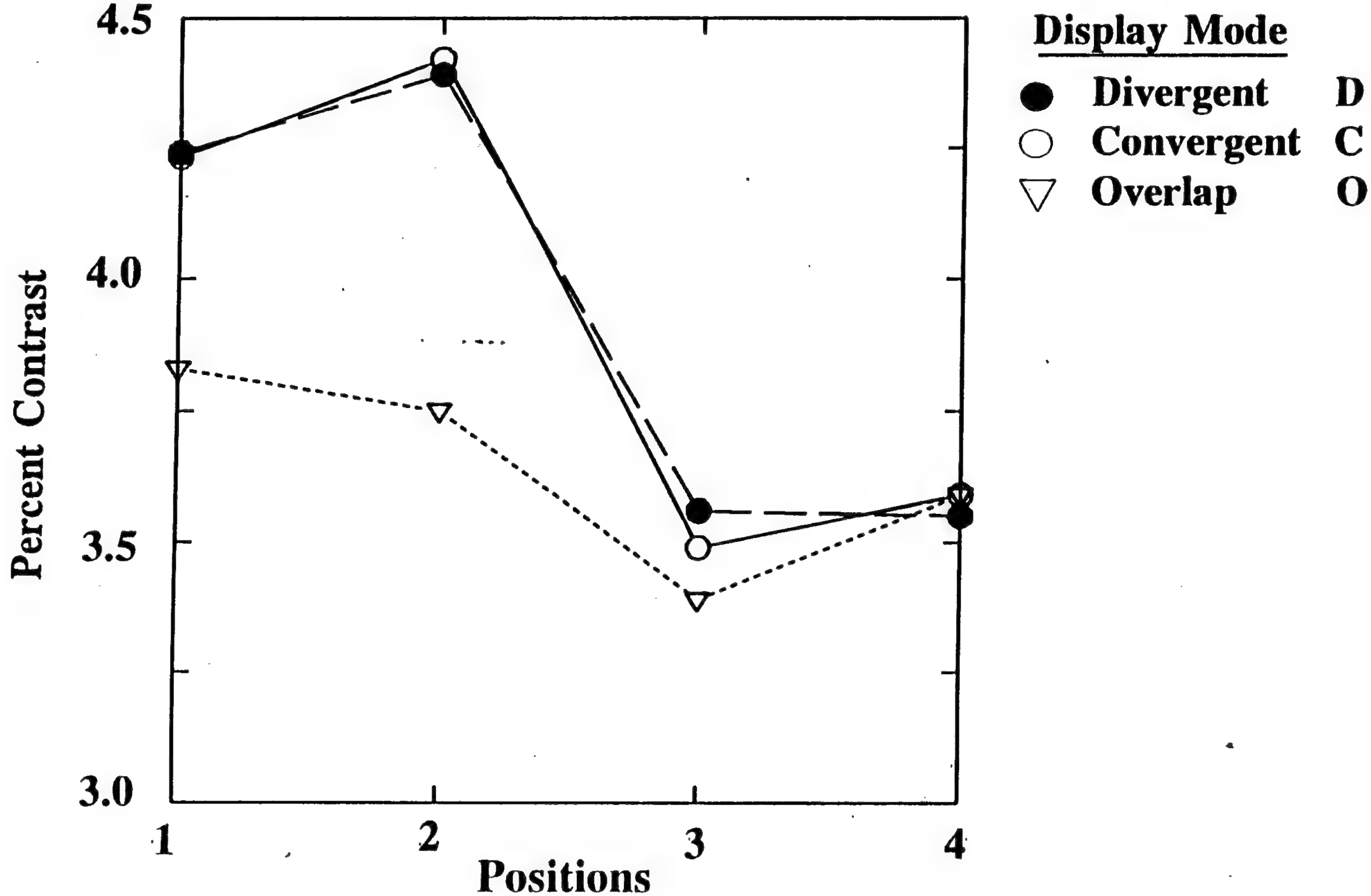
t-test

p<

t-test				
C v D	NS	NS	NS	NS
O v C	*	*	NS	NS
O v D	.0005	*	NS	NS

* = p<.0001

1.06 cpd 3.75 Hz

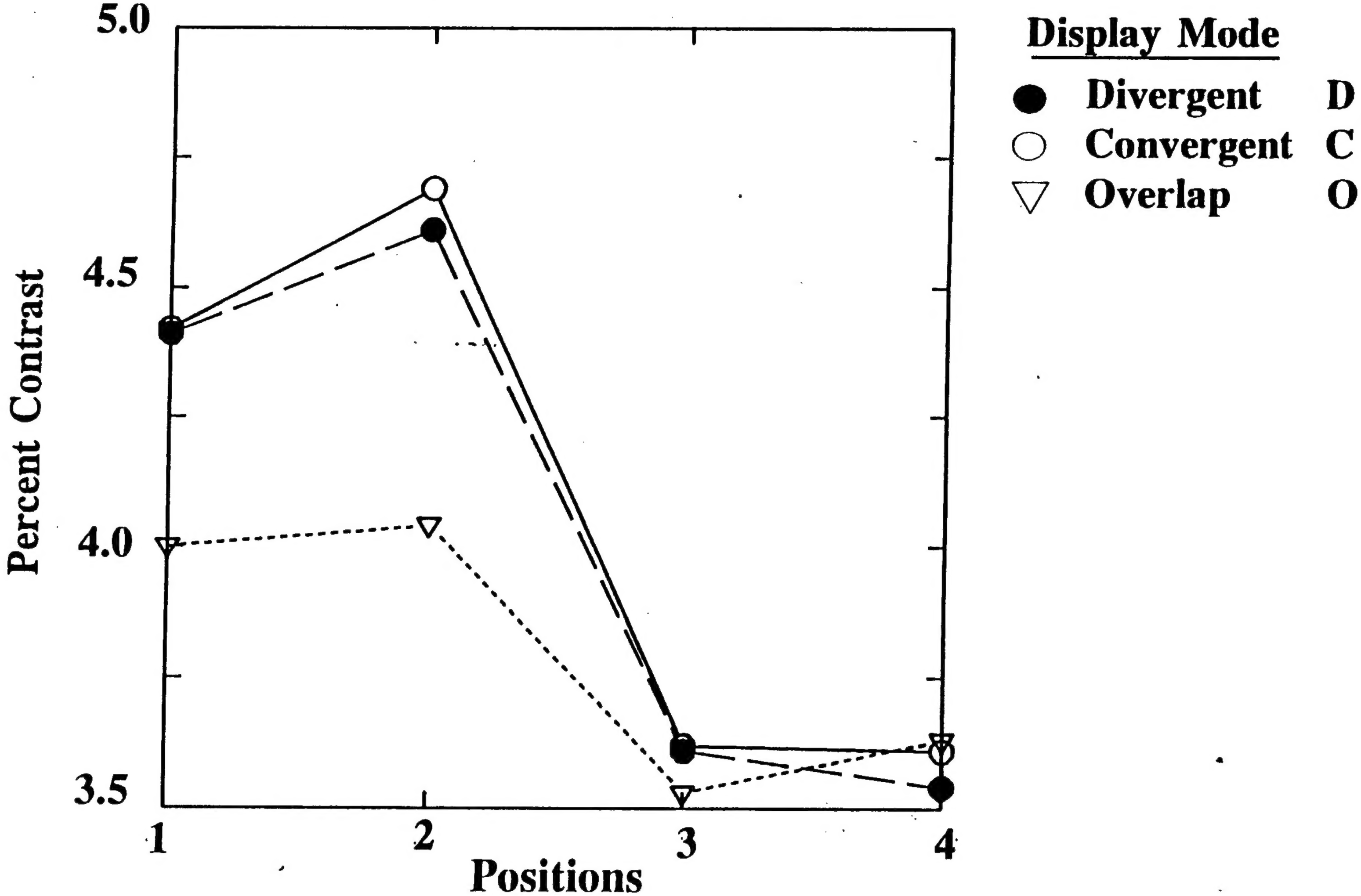


p<

t-test				
C v D	NS	NS	NS	NS
O v C	*	*	NS	NS
O v D	*	*	.025	NS

* = p<.0001

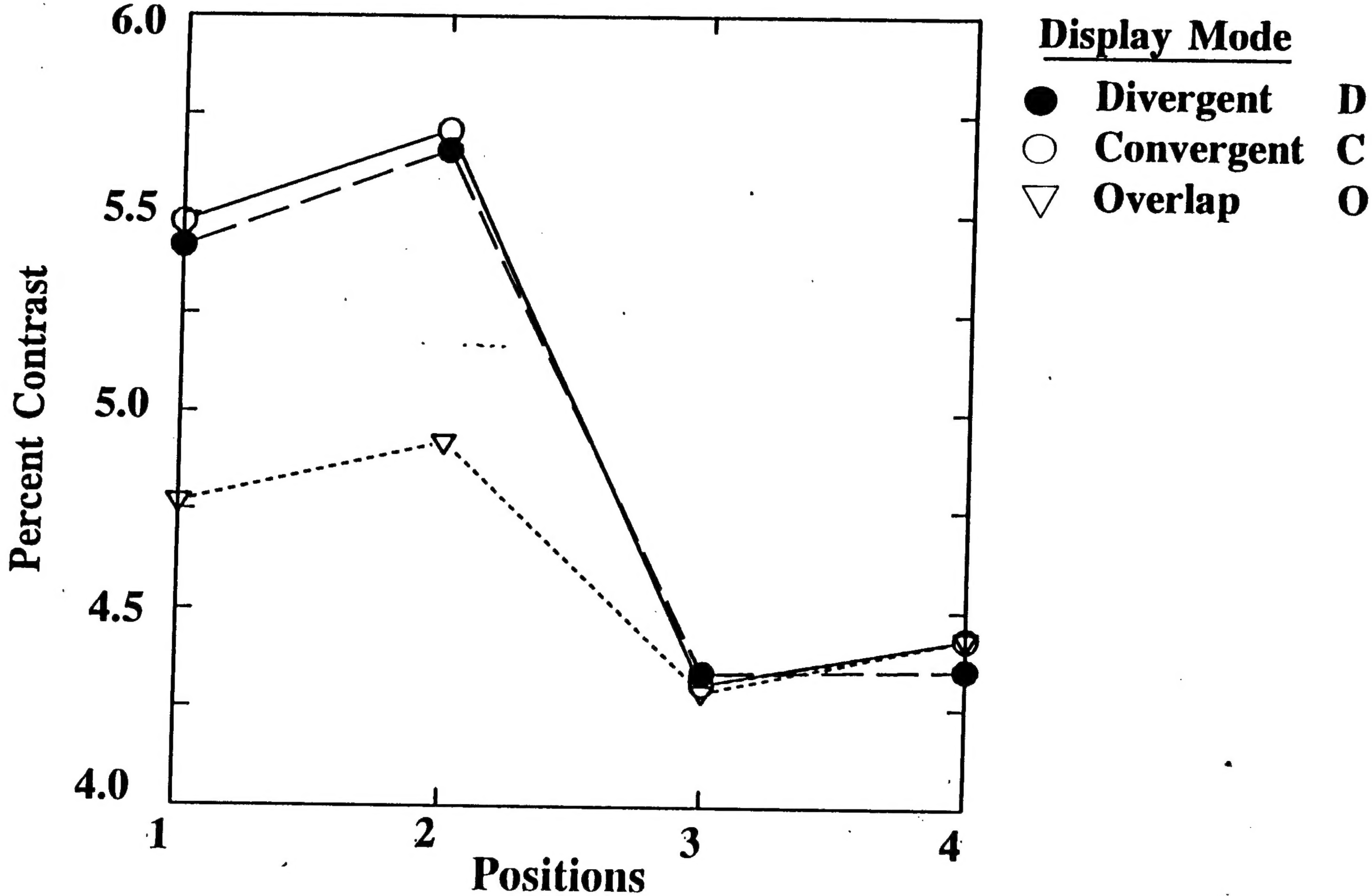
1.06 cpd 7.5 Hz



t-test	p<			
C v D	NS	NS	NS	NS
O v C	.0005	*	NS	NS
O v D	.0005	*	NS	NS

* = p<.0001

1.06 cpd 15 Hz



p<

t-test	1	2	3	4
C v D	NS	NS	NS	NS
O v C	.0001	*	NS	NS
O v D	*	*	NS	NS

* = p<.0001

Conclusions

As expected, for positions 1 and 2, contrast thresholds were higher for the monocular probes in the Convergent and the Divergent display modes than for the binocular probes in the complete Overlap display mode.

For high spatial frequency probes, these contrast thresholds were higher in the Divergent than in the Convergent mode. Thresholds were higher, and the divergent convergent difference was greater, for monocular positions adjacent to the monocular/binocular border.

In positions 3, thresholds were, in some cases, higher in the Convergent and Divergent modes than in the Overlap mode showing the influence of the adjacent monocular/binocular border on binocular probe stimuli.

A number of factors are implicated, including binocular rivalry and suppression, color brightness spreading, and edge effects (see references), which we will discuss elsewhere. In brief, we ecologically model the display modes (see Barrand, 1979; Gibson, 1979; Melzer and Moffitt, 1989, 1991) in terms of what has come to be known as DaVinci stereopsis (Nakayama and Shimojo, 1990) and analyze the visual system's responses to different ecological interpretations of the visual world (see Shimojo and Nakayama, 1989).

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